LEAP 2013 Uppsala

ROYAL INSTITUTE OF TECHNOLOGY

Polarizing antiprotons for FAIR

– Overview of PAX experiments –

Pia Thörngren Engblom
On behalf of the PAX Collaboration

Polarized Antiproton eXperiments

PAX Collaboration

Spokespersons:
Paolo Lenisa, INFN, lenisa@fe.infn.it
Frank Rathmann, FZJ, f.rathmann@fz-juelich.de

Joint Research Activity HadronPhysics2&3
WP25: PolAntiP - Polarized Antiprotons
Frank Rathmann, FZJ

ERC-2009-AdG POLPBAR PI:
Hans Ströher, FZJ, h.stroeher@fz-juelich.de

180 Physicists 35 Institutions (15 EU, 20 NonEU)

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Outline

- Goal
  - intense beams of polarized antiprotons
- Motivation
  - new research field, transversity
- Method
  - spin filtering
- Milestones
  - COSY Experiments proof-of-principle
- Proposed
  - CERN/AD Experiment with antiprotons
  - FAIR upgrade
- Summary

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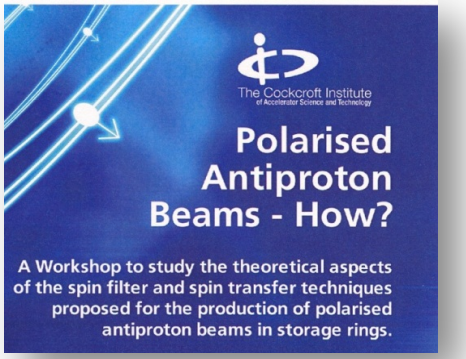
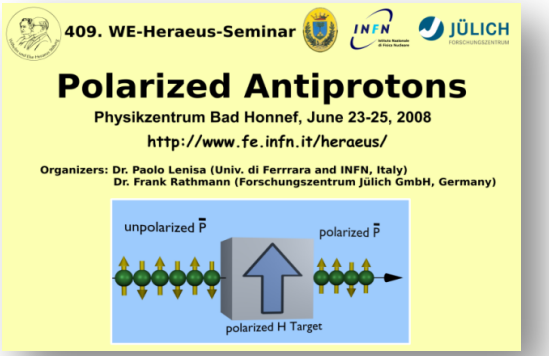


Goal-of-PAX



- **Demonstrate an efficient method for polarizing an antiproton beam →**

  a new field of hadron physics

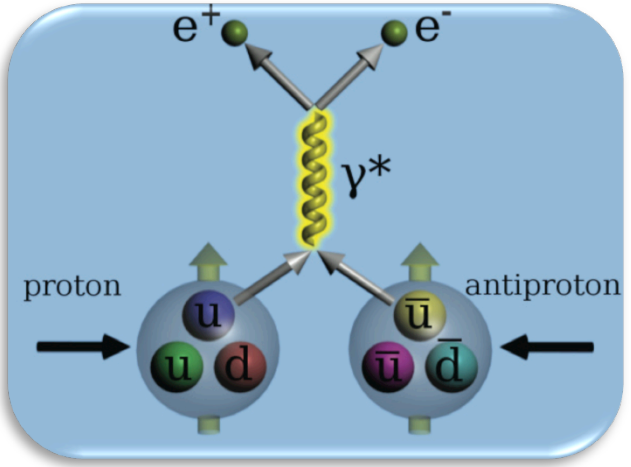
  - **Polarized antiprotons to be employed at CERN and at FAIR**

- Proposed methods…
- Antihyperon decay – low intensity secondary beam < 10^5 s^{-1}
- **Selective spin flip (tested by PAX – not useful!)**
- **Selective spin loss (spin filtering – proved to work – FILTEX & PAX!)**
  - …More ideas (none shown to work ☹)…
  - Channeling in crystals
  - Spin splitter (repeated Stern-Gerlach)
  - Dynamic nuclear polarization in flight (Krisch@Bodega-BAY 1985)

Motivation I – Transversity of the proton

- **A_{TT}** →

– First *direct* measurement of the transversity –
Doubly polarized Drell-Yan reactions:
annihilation of the valence quark-antiquarks in the proton-antiproton



$$A_{TT} \equiv \frac{d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}}{d\sigma^{\uparrow\uparrow} + d\sigma^{\uparrow\downarrow}} = \hat{a}_{TT} \frac{\sum_q e_q^2 \, h_1^q(x_1, M^2) \, h_1^{\bar{q}}(x_2, M^2)}{\sum_q e_q^2 \, q(x_1, M^2) \, \bar{q}(x_2, M^2)}$$

where $\hat{a}_{TT} = \frac{\sin^2\theta}{1 + \cos^2\theta} \cos 2\phi$

Motivation II – see TechProposal arXiv:hep-ex/0505054

- **Proton electromagnetic form factors**

–Moduli and absolute phase of the proton em form factors in the time-like region

- **Doubly polarized antiproton-proton hard scattering**

–To be compared to the analogue pp measurement

- **Hadron spectroscopy** – Exotic states

Report on the PAC QCD meeting of 14,15 June 2004

The PAC considers the spin physics of extreme interest and the building of an antiproton polarized beam as a unique possibility for the FAIR project, but does not approve the letters of intent asking for a more detailed study of achievable antiproton polarization and the anticipated physics results.

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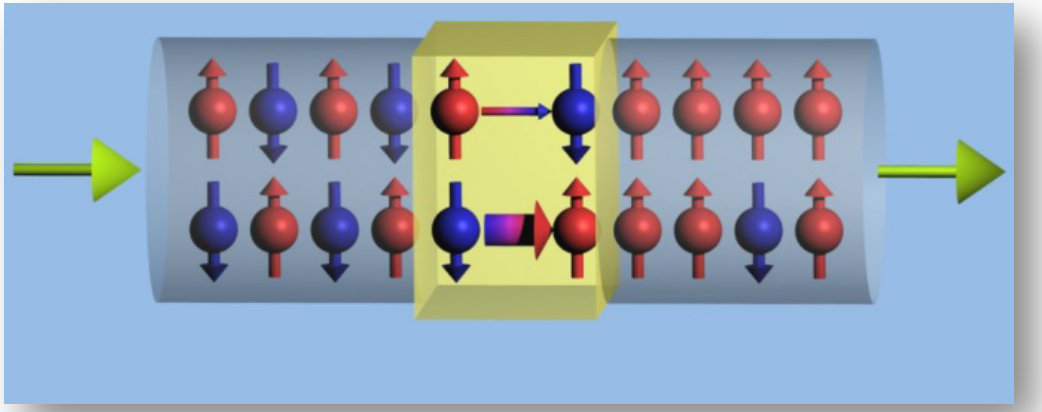
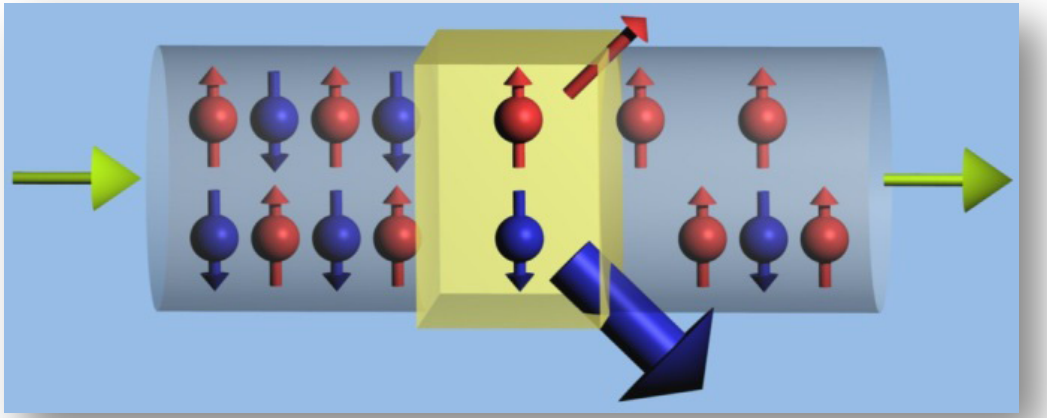
Methods: How2 polarize a stored beam?

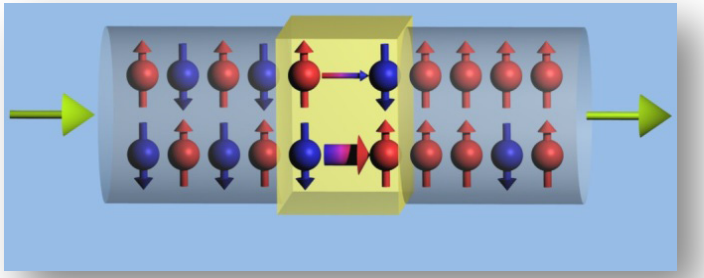
- Spin flip



- Spin filter



Method I – Spin flip



- Using spin-dependent interaction leptons-hadrons: spin-flip

Method proposed by T. Walcher, H. Arenhoevel et al (Mainz): Eur. Phys. J. A34 (2007) 447.

- Huge spin transfer cross section (H. Arenhoevel 2007) in attractive systems like e+p(bar) or e-p predicted: **10^{13} barn** at low relative velocities!
- A calculation of the same quantity by Milstein and co-workers [NIM B 266 (2008) 3453] resulted in **σ = 0.75 mb**.
- ***Resolved by PAX Experiment:***

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Physics Letters B 674 (2009) 269–275

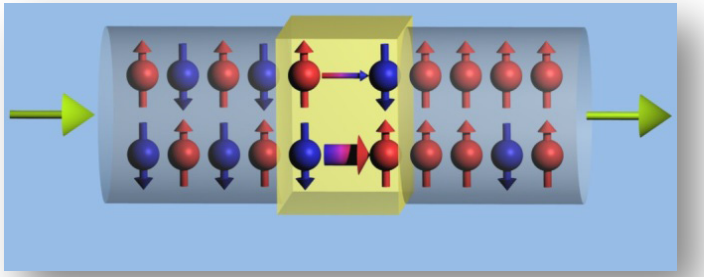
Polarizing a stored proton beam by spin flip?

www.elsevier.com/locate/physletb

Erratum Eur. Phys. J. A **39**, 137–138 (2009)

A surprising method for polarising antiprotons

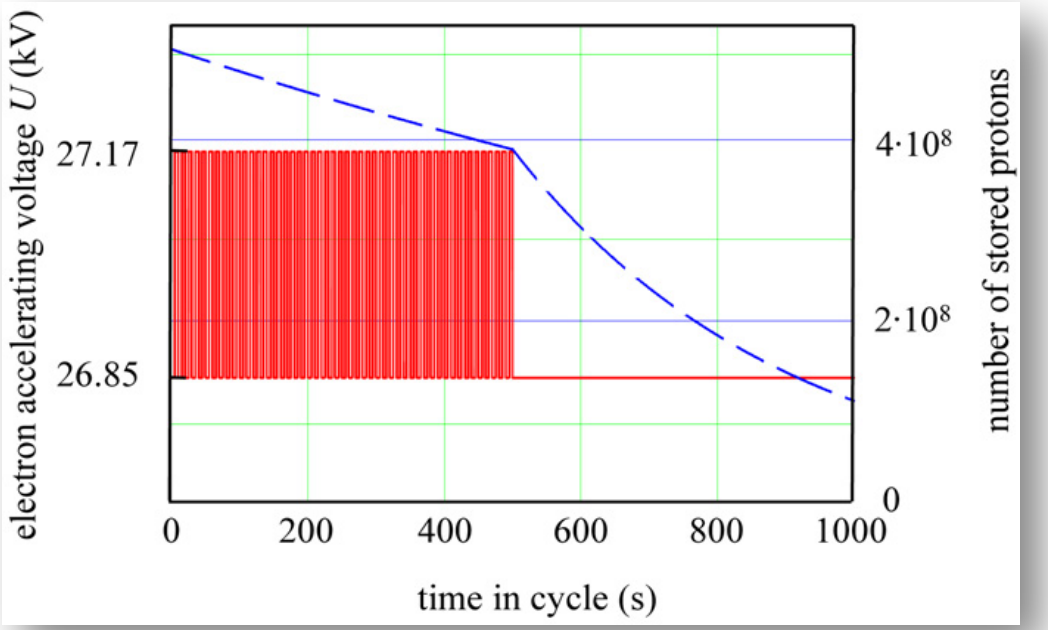
Method I – Milestone I

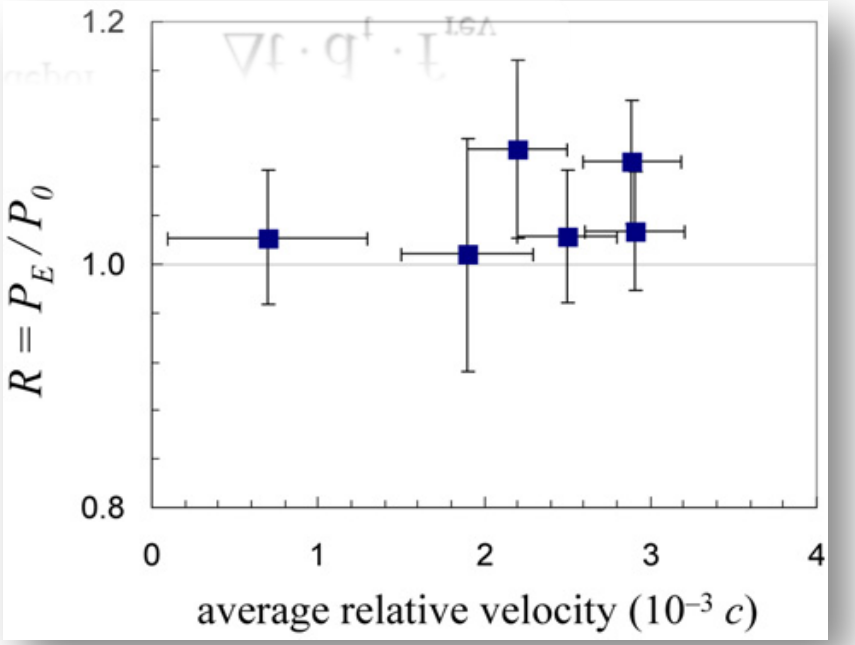


- PAX@COSY
- Using a polarized proton beam and co-moving electrons as target – no depolarization seen

$$\sigma_{depol} = \frac{-\ln\left(\frac{P_{detuned}}{P_{nominal}}\right)}{\Delta t \cdot d_t \cdot f_{rev}}$$

$< 10^7$ b





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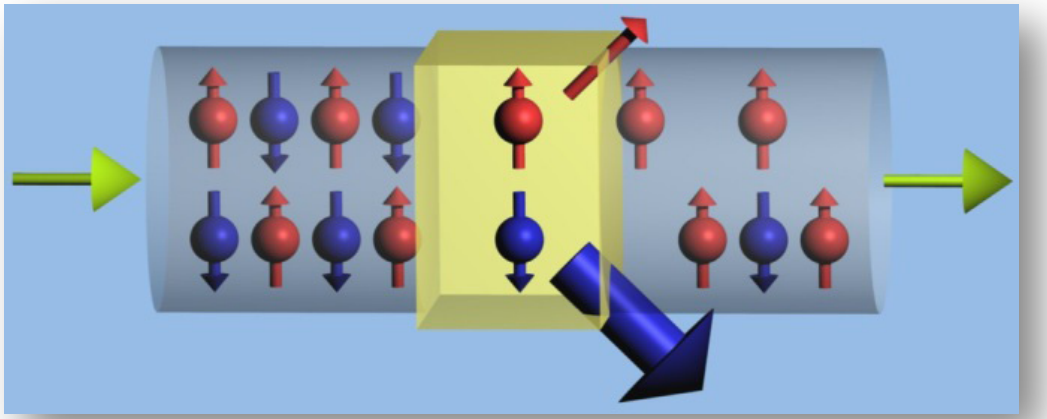
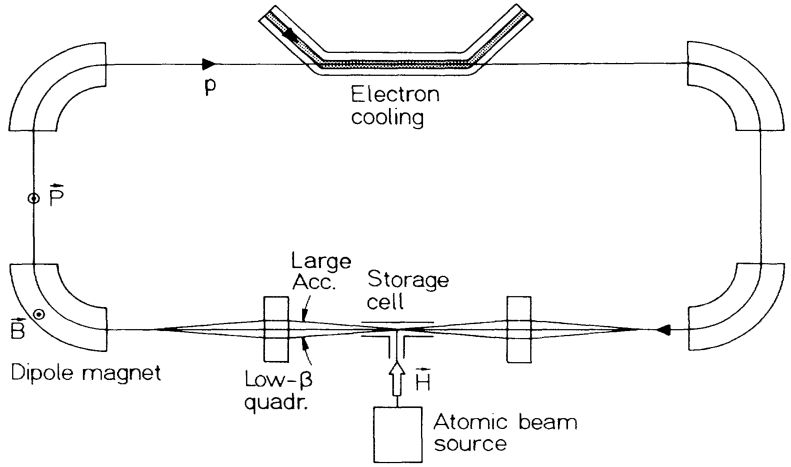
Method II

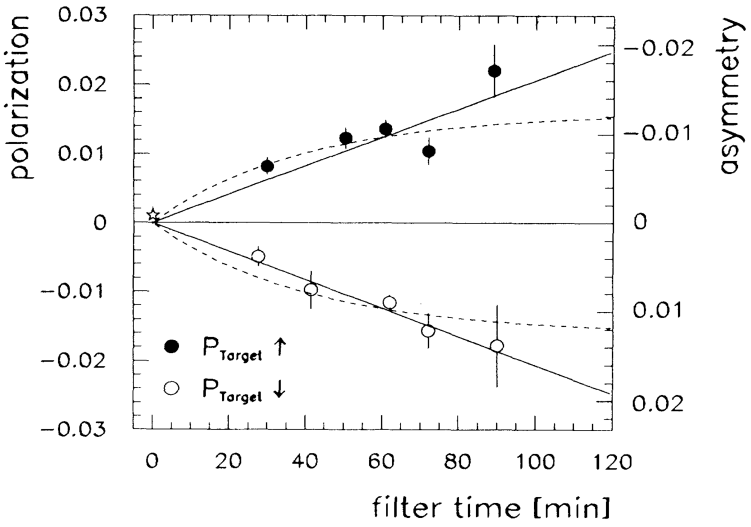
- Spin filtering



Rathmann et al., PRL 71, 1379 (1993)

FILTEX@TSR/Heidelberg proof-of-principle proton-proton spin filtering





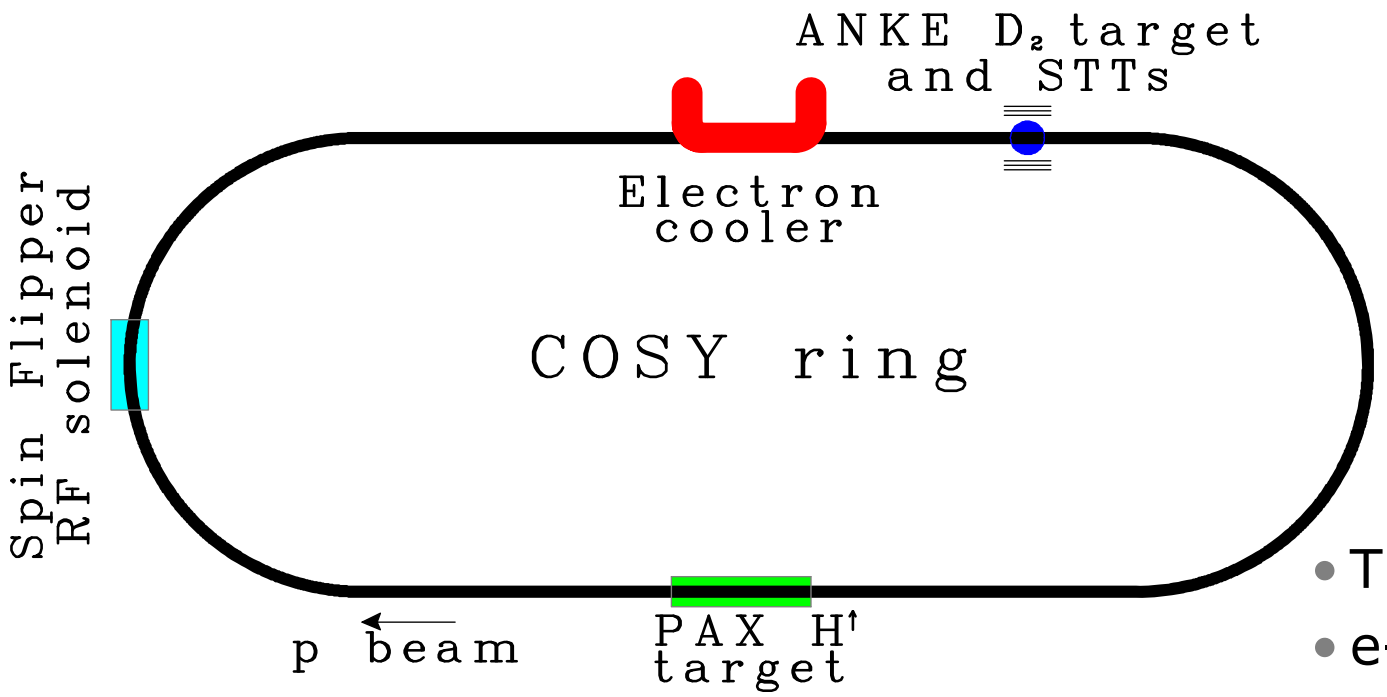
- Tbeam = 23 MeV (unpolarized protons)
- Target:
  - storage cell fed by ABS
  - dt=6 x 10^13 atoms/cm2
  - guide field 5G: up/down
- Filtering for 90 min

$$\sigma(\Theta) = \sigma_0(\Theta)\,[1 \pm A_{xx}(\Theta) P_B P_T]$$

$$\epsilon = (N_\uparrow - N_\downarrow)/(N_\uparrow + N_\downarrow)$$

$$P_B = \epsilon / A_{xx} P_T$$

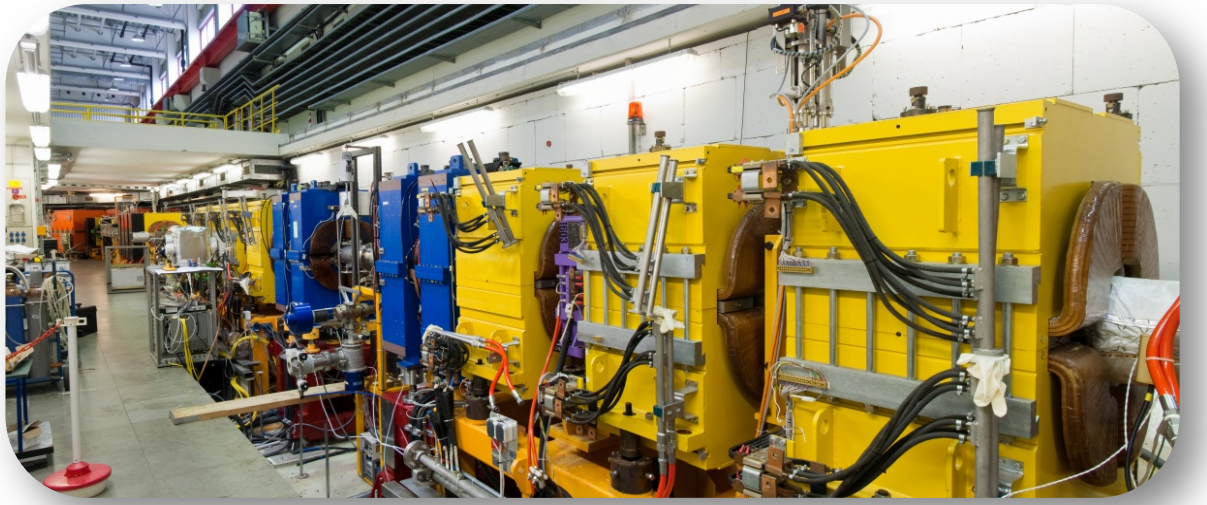
Method II - Milestone II: PAX@COSY proton-proton spin filtering

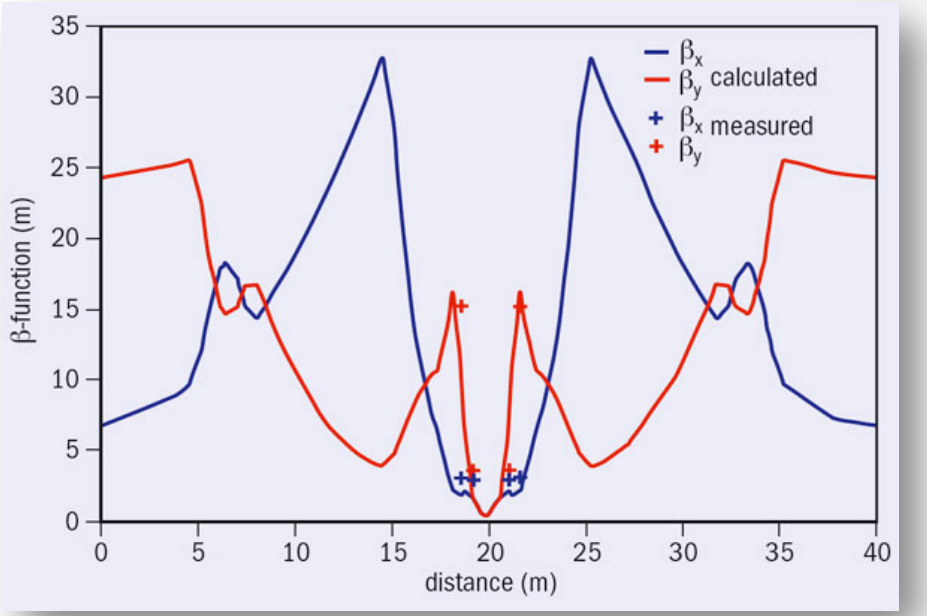


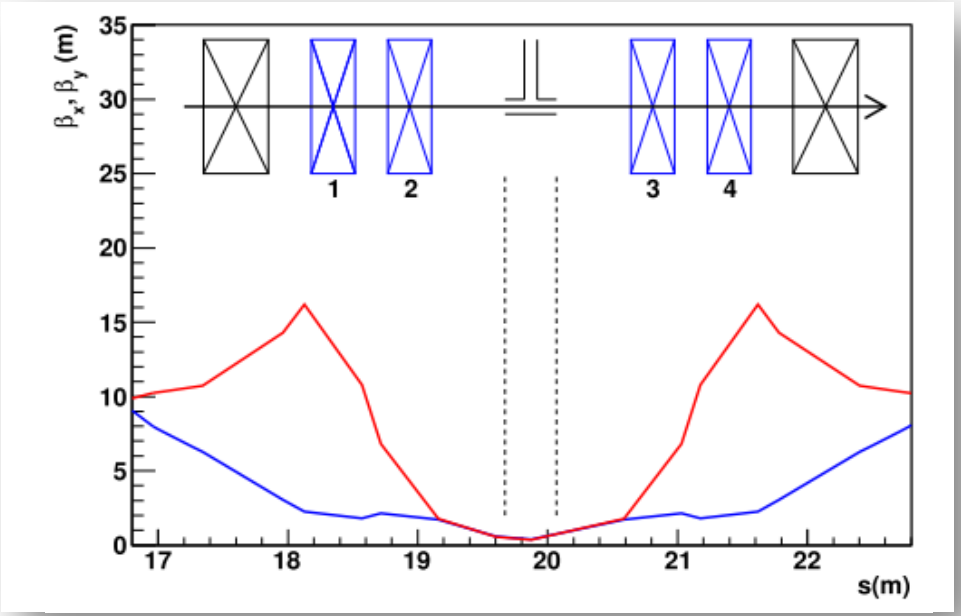
- Tbeam = 49.3 MeV
- e-cooling
- ABS filtering target
- D2 unpol target
- Left-Right detectors

PAX@COSY

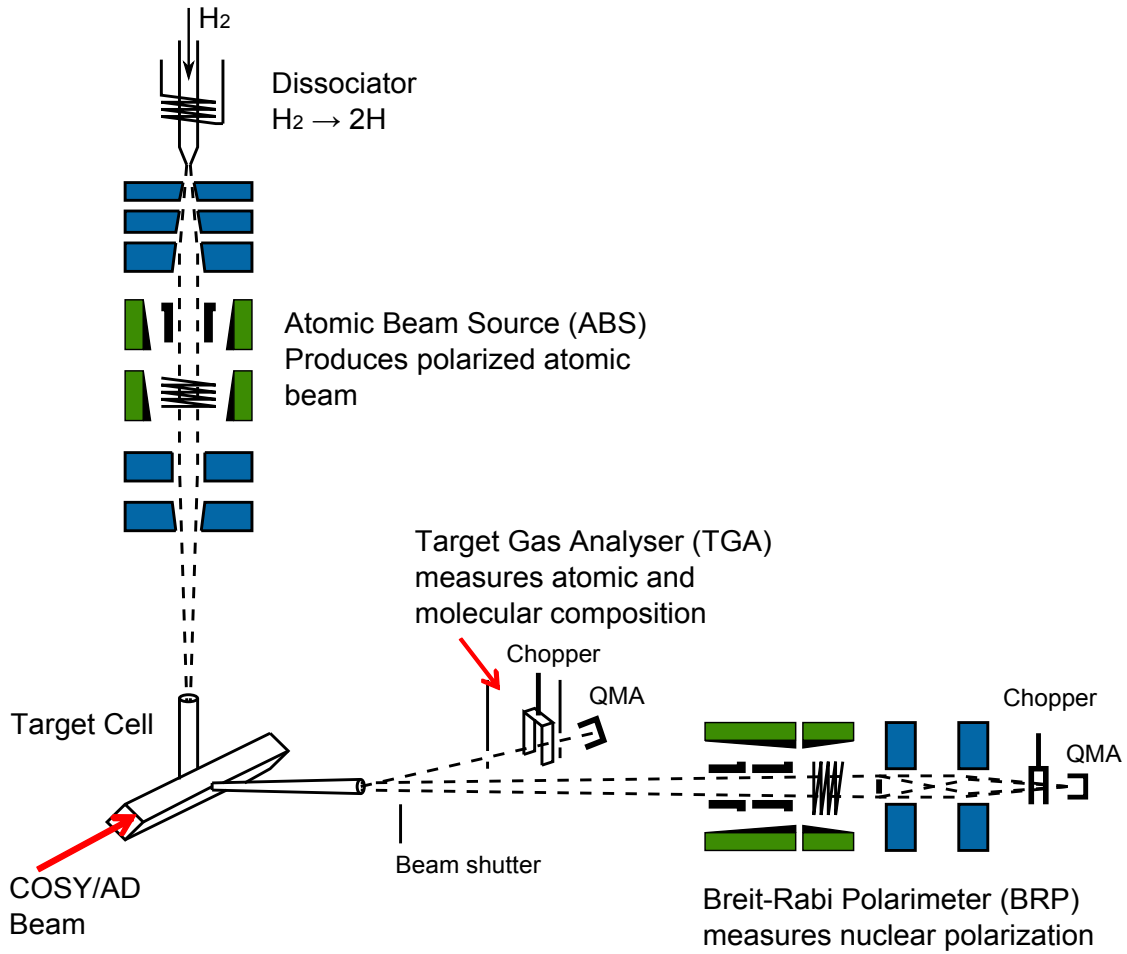
- Low beta section developed & commissioned

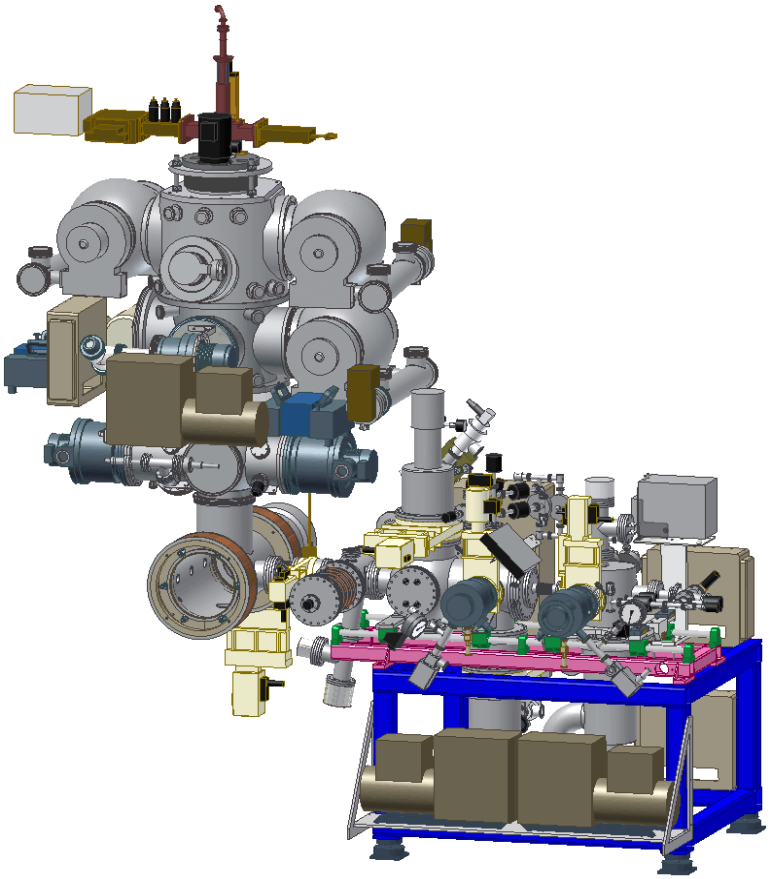






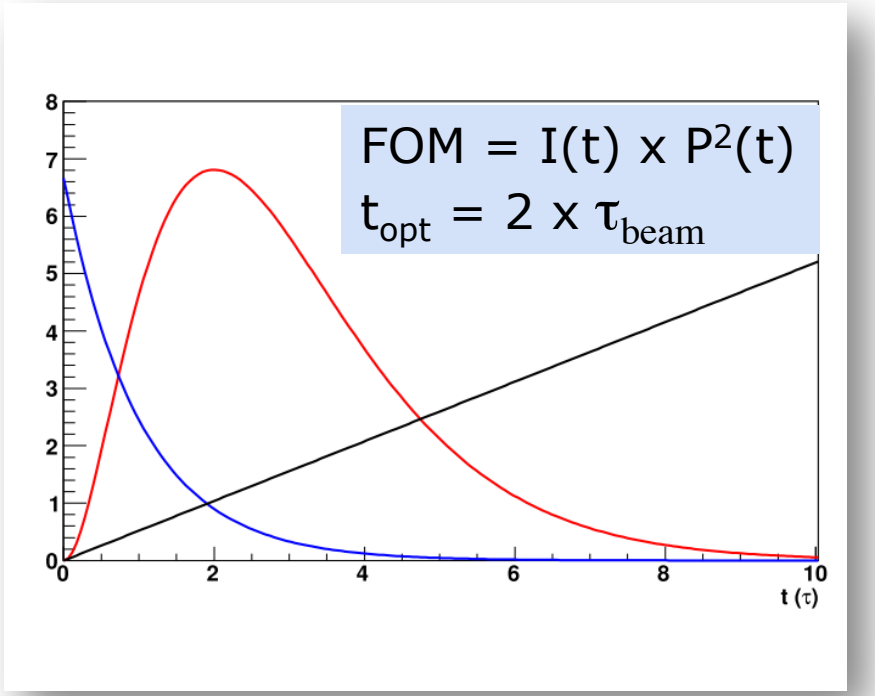
PAX@COSY – polarized filtering target

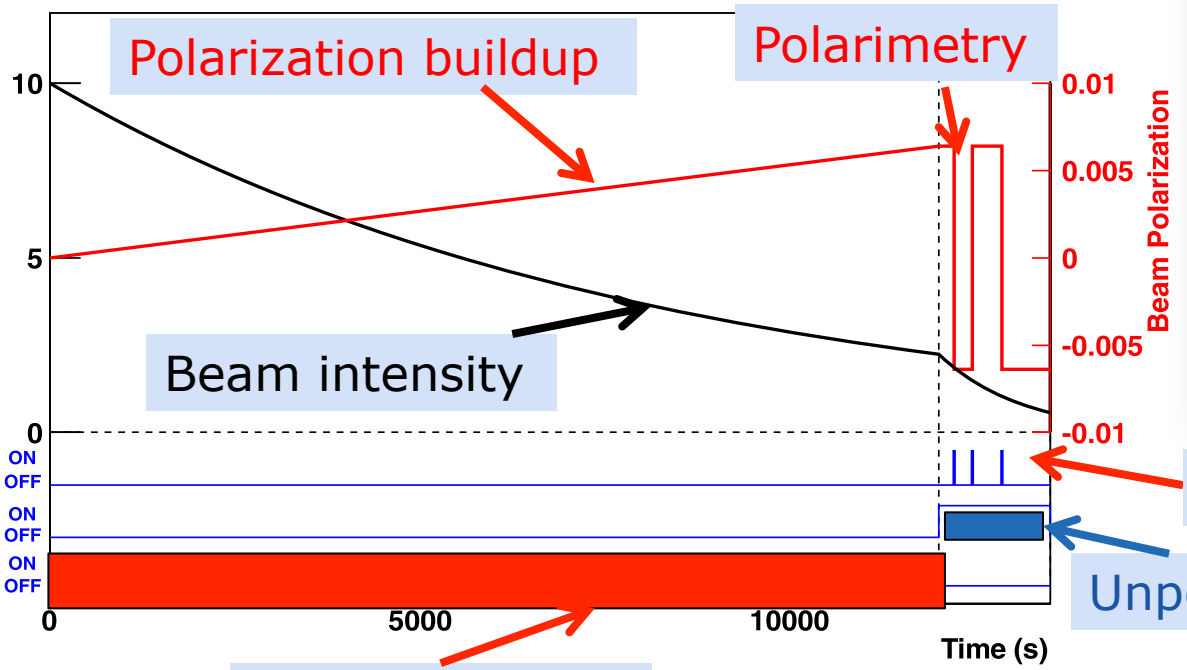




PAX@COSY – spin filtering cycle

- Filtering for 2 x τ_{beam}
- Measuring P_{beam}





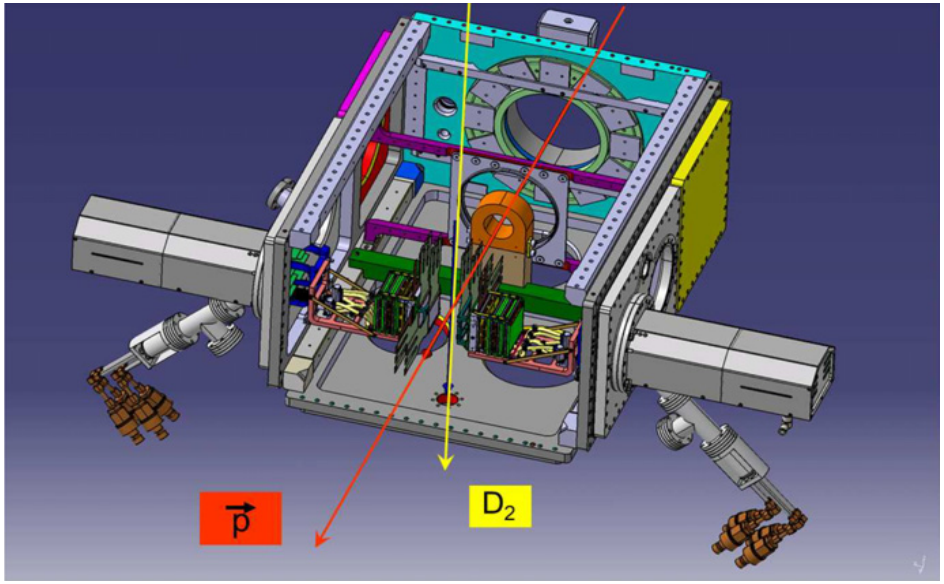
Spin flipper

Unpolarized d-target

Filtering tgt ON

PAX@COSY – beam polarization measurement (pol)pd elastic

- ANKE D_2 target



$$\frac{d\sigma}{d\Omega}(\theta,\phi) = \frac{d\sigma_0}{d\Omega}\left[1 + P A_y(\theta) cos\phi\right]$$

Using the cross-ratio method:

$$\delta = \sqrt{\frac{Y_{L\uparrow}(\theta,\phi)\cdot Y_{R\downarrow}(\theta,\phi)}{Y_{L\downarrow}(\theta,\phi)\cdot Y_{R\uparrow}(\theta,\phi)}} = \frac{1 + P A_y(\theta)}{1 - P A_y(\theta)}$$

$$\epsilon = \frac{\delta - 1}{\delta + 1} = P A_y \langle cos\phi \rangle$$

Polarization buildup 0.002/h → Precison of experiment

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Physics Letters B 718 (2012) 64–69

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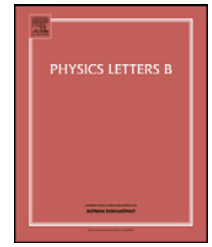
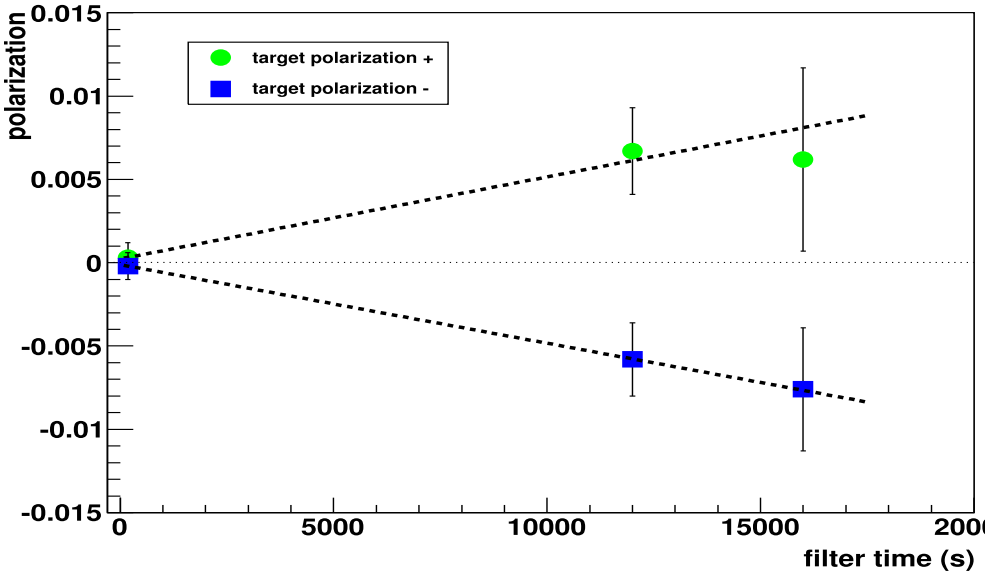
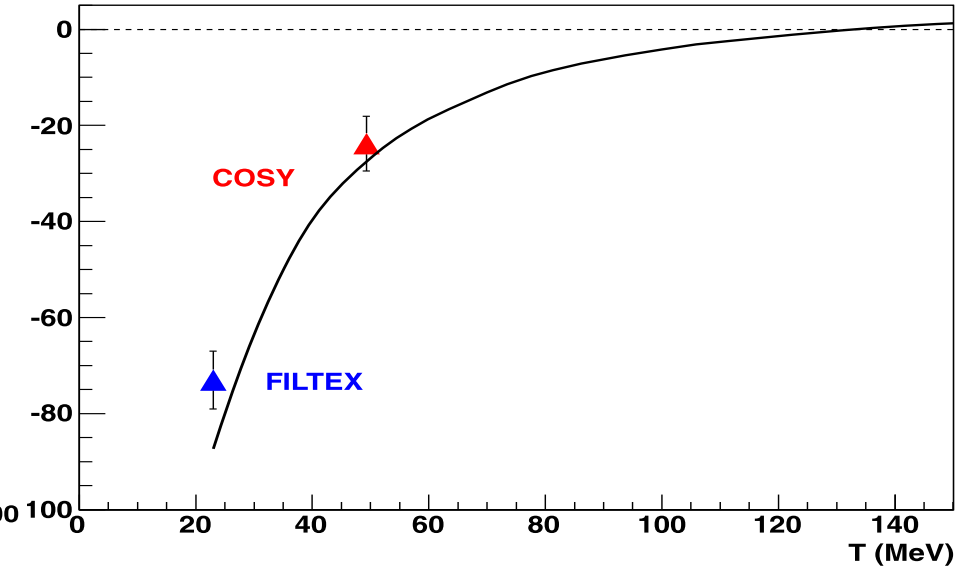


Polarization of a stored beam by spin-filtering





Spin filtering is a viable method – the best option for polarizing an antiproton beam

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PAX@CERN/AD - proposal

- ✓Commissioned the new PAX facility at COSY for implementation at CERN/AD
- ✓Disproven the use of a co-moving polarized lepton beam as polarizer of a stored hadron beam in situ
- ✓Confirmed the spin filtering method as the viable method for polarization of a stored hadron beam

Measurement of the Spin–Dependence of the pbar-p Interaction at the AD–Ring
CERN-SPSC-2009-012 ; SPSC-P-337 (April 2009)

Predictions I spinfiltering pbar p

PHYSICAL REVIEW C **87**, 054003 (2013)

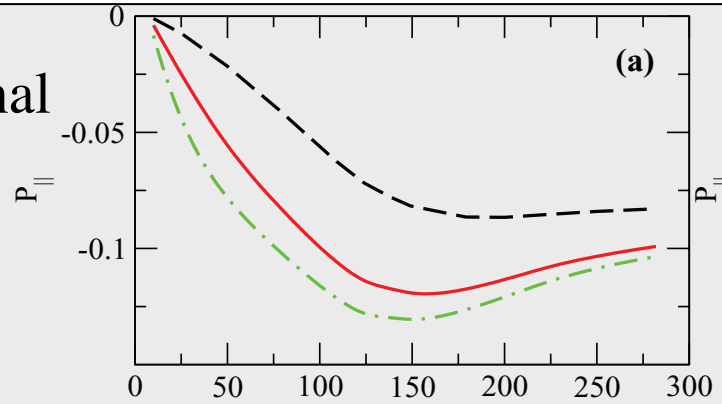
Elastic $\bar{p}d$ scattering and total $\bar{p}d$ cross sections

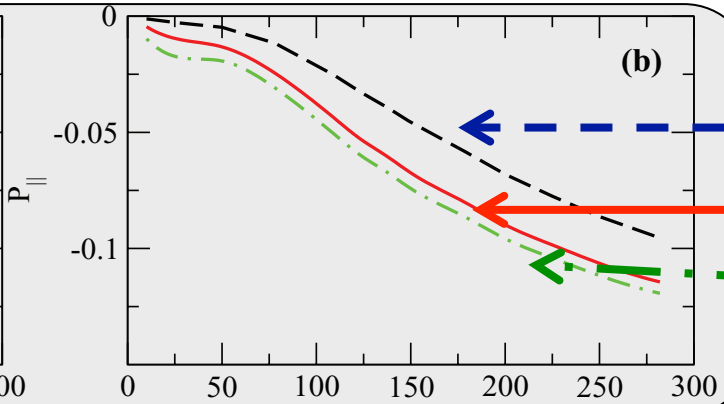
Yu. N. Uzikov[1,2] and J. Haidenbauer[3,4]

Model A

Model D

Longitudinal tgt pol





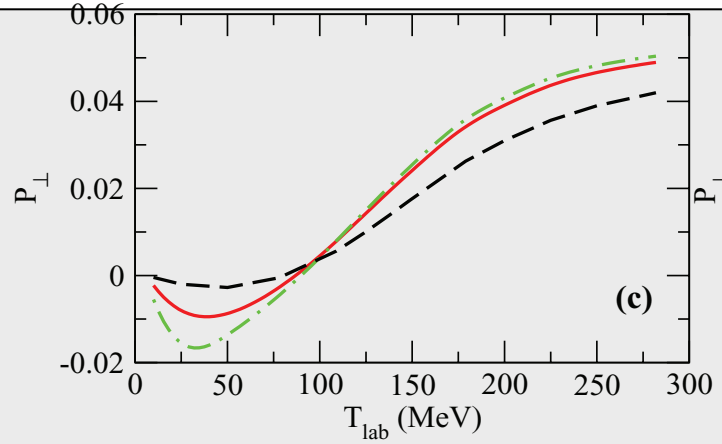
Acceptance

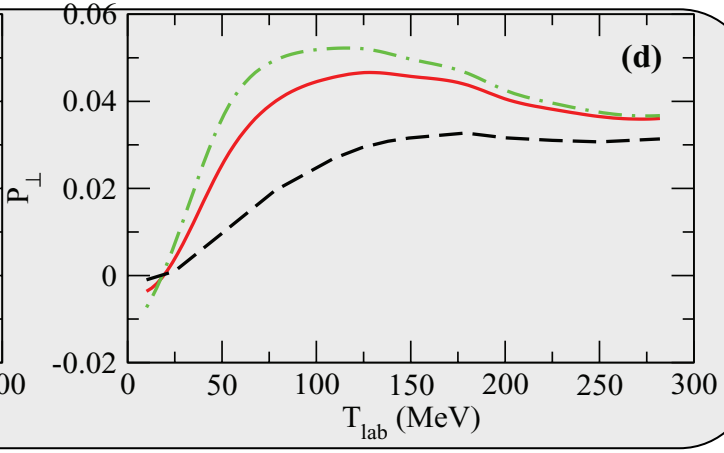
10 mrad

20

30

Transverse tgt pol





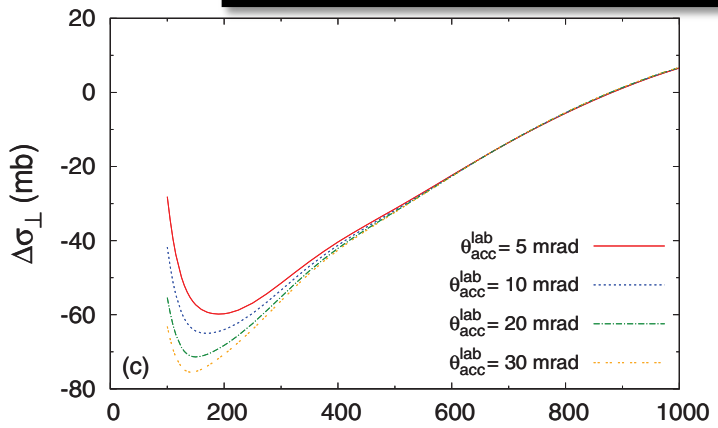
Polarization after 2τbeam

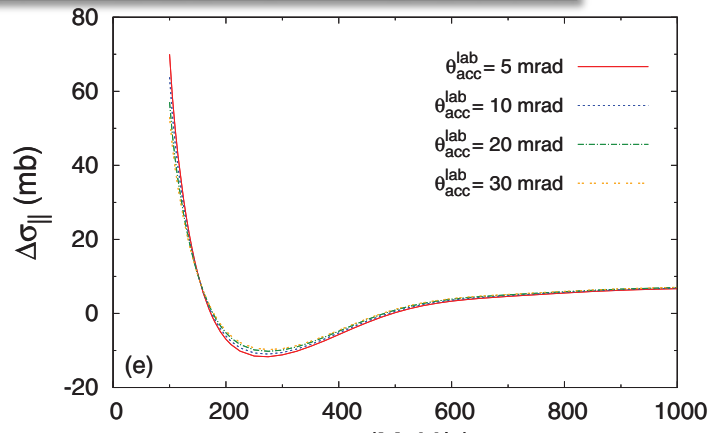
Predictions II spinfiltering pbar p

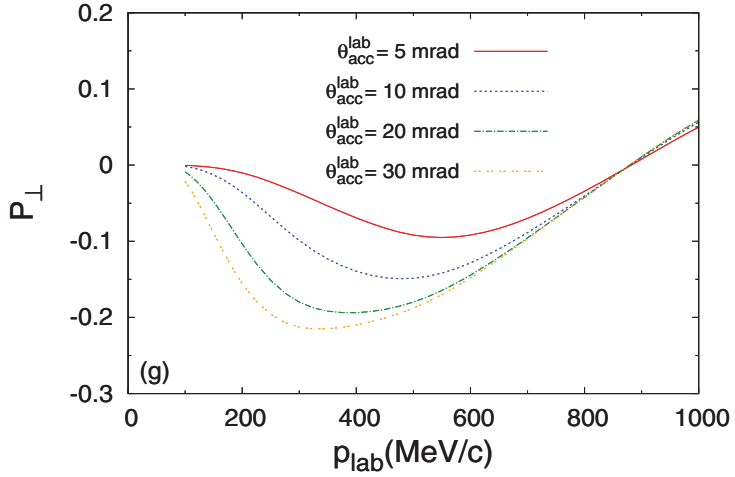
PHYSICAL REVIEW C **87**, 054005 (2013)

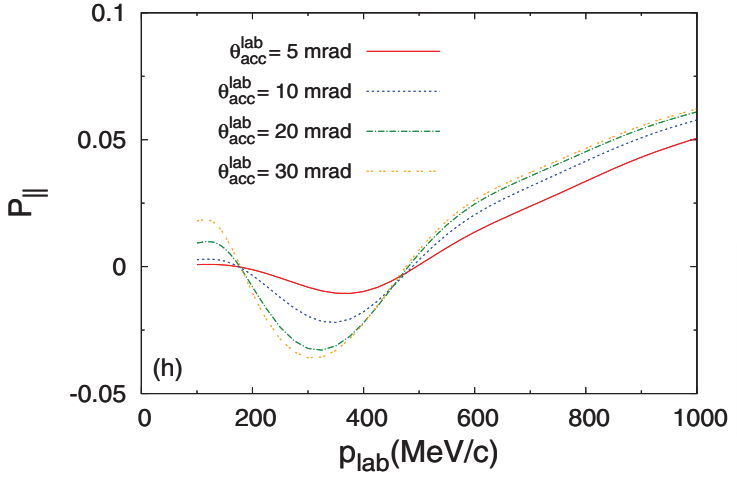
Polarization observables in low-energy antiproton-proton scattering

Daren Zhou and Rob G. E. Timmermans



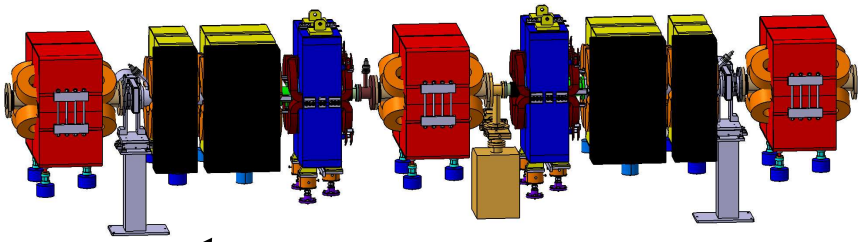


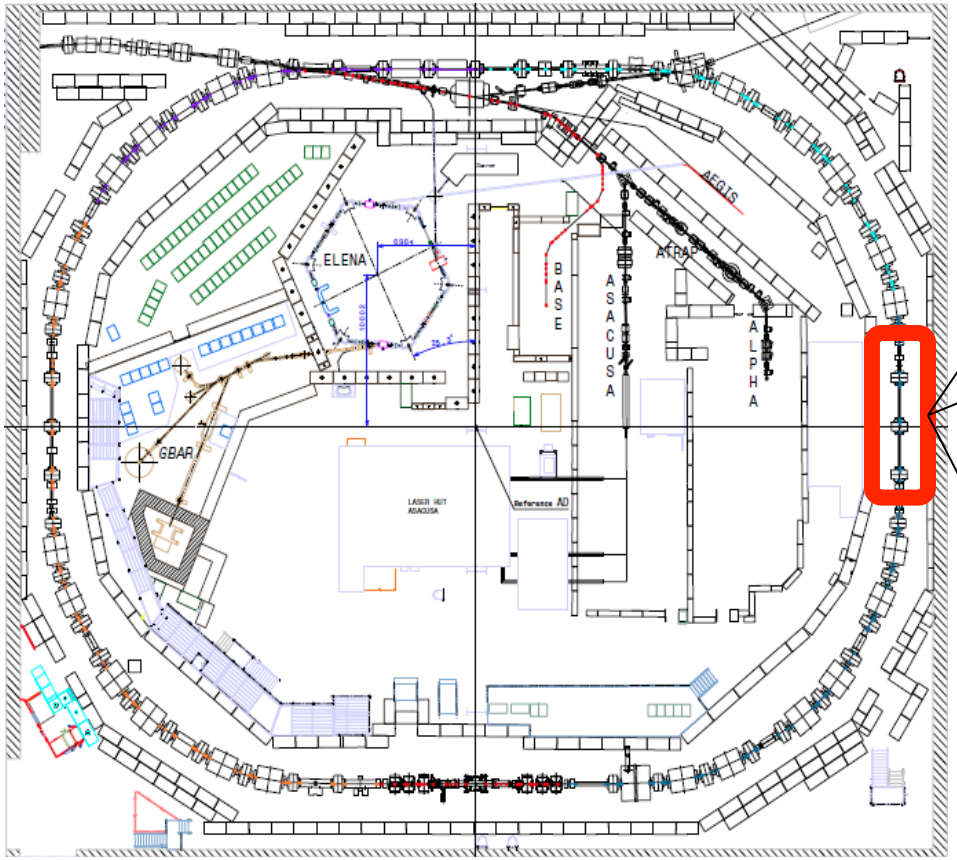




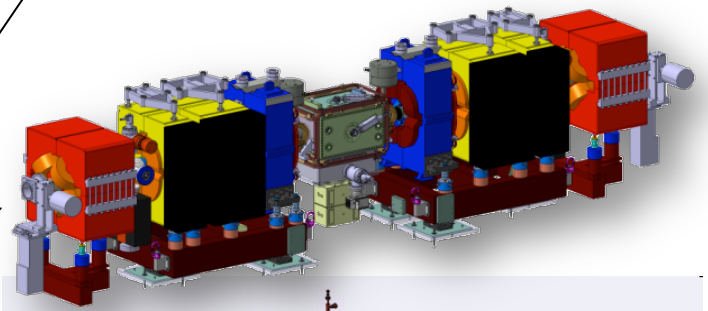
Polarization after 2τbeam

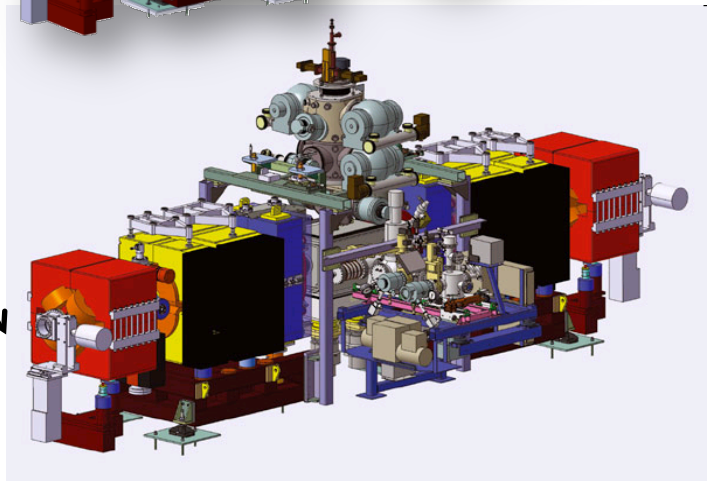
PAX@AD/CERN





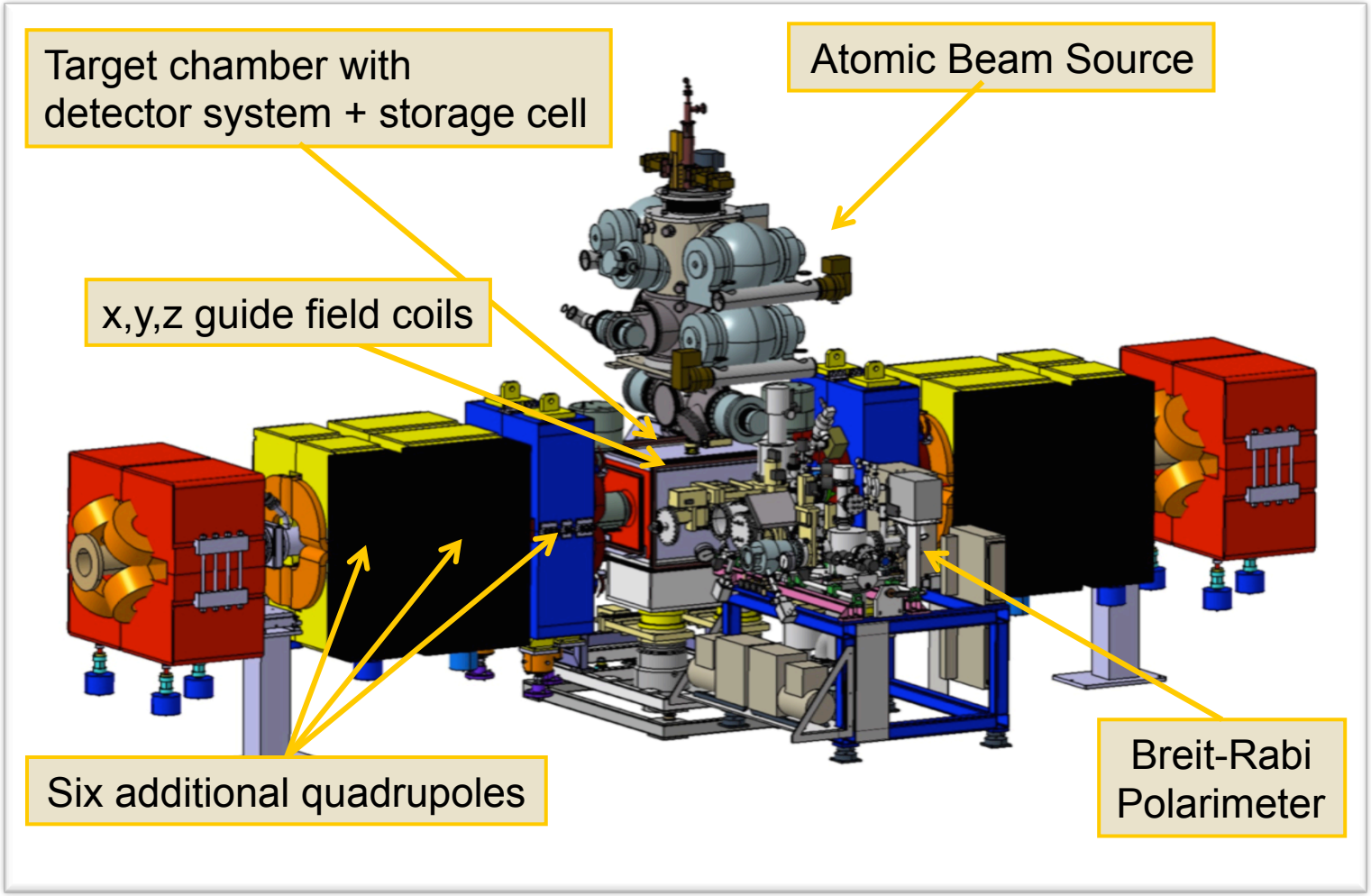
Stepwise approach



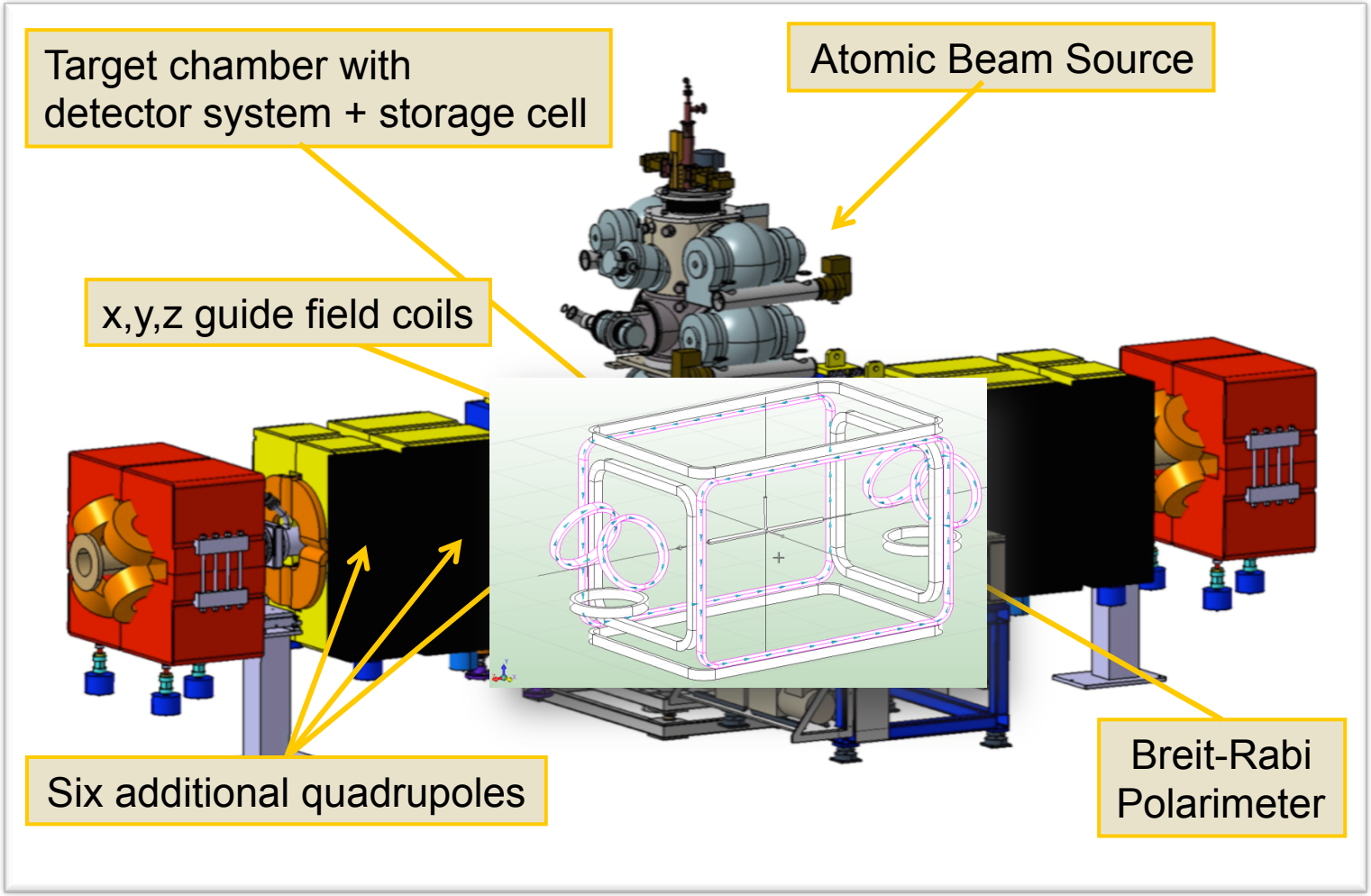


PAX target section

PAX@AD/CERN


Target chamber with
detector system + storage cell
Atomic Beam Source
x,y,z guide field coils
Six additional quadrupoles
Breit-Rabi
Polarimeter

PAX@AD/CERN


Target chamber with
detector system + storage cell
Atomic Beam Source
x,y,z guide field coils
Six additional quadrupoles
Breit-Rabi
Polarimeter

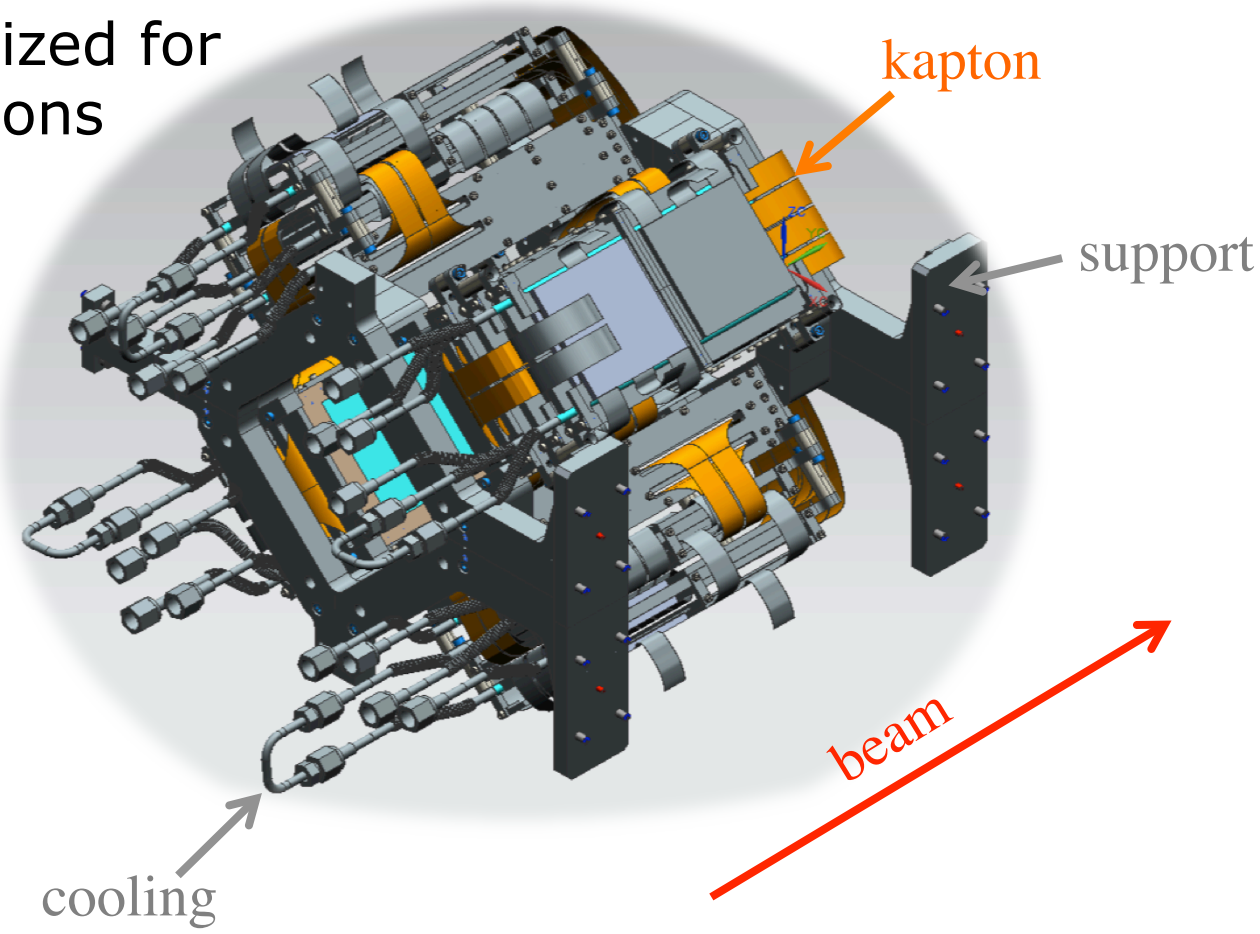
PAX detector development
COSY & AD

V. Carassiti, P. Lenisa

Detection system optimized for spin-filtering of antiprotons

Measure φ-dependence of spin observables

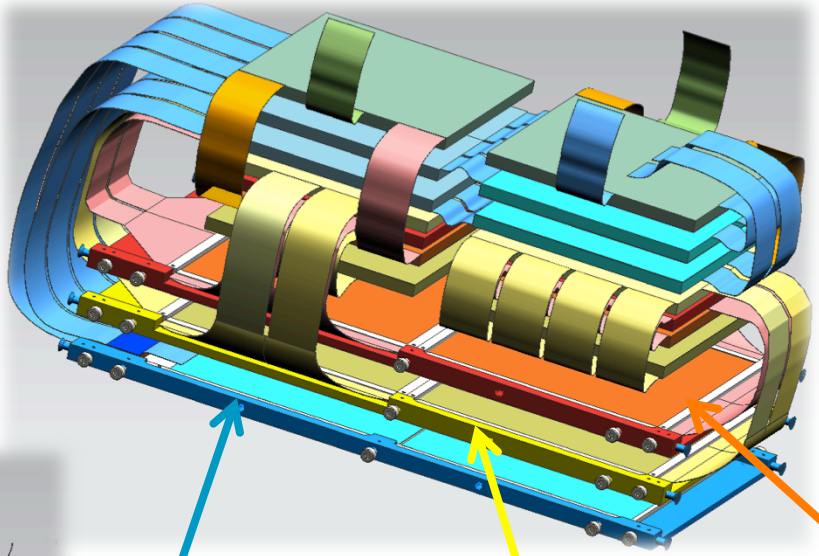
Versatile for other experiments e.g.
pd breakup
All 22 independent observables accessible

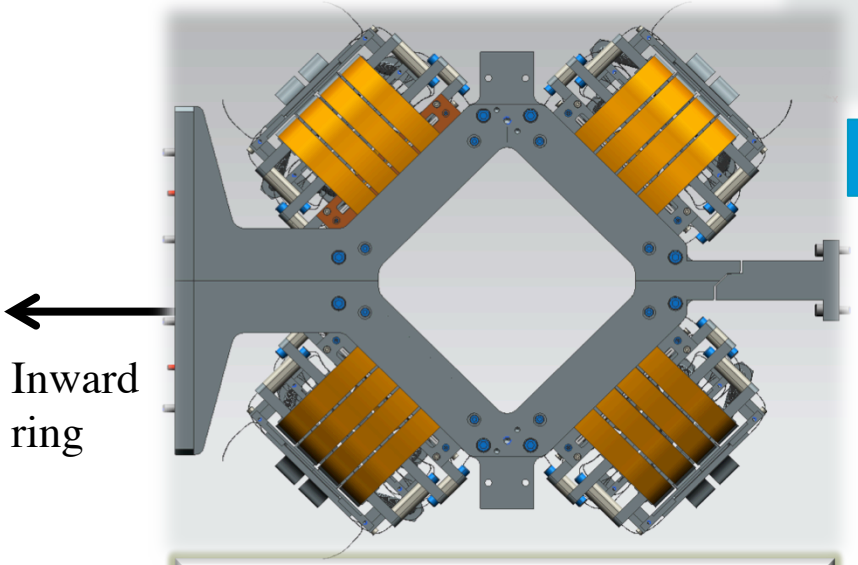


PAX detector development
COSY & AD

V. Carassiti, P. Lenisa

3 detector layers
φ−symmetric
4 quarters





Detector setup front view

Double-sided silicon strip sensors
Pitch 0.7 mm → vertex resolution ≤ 1mm

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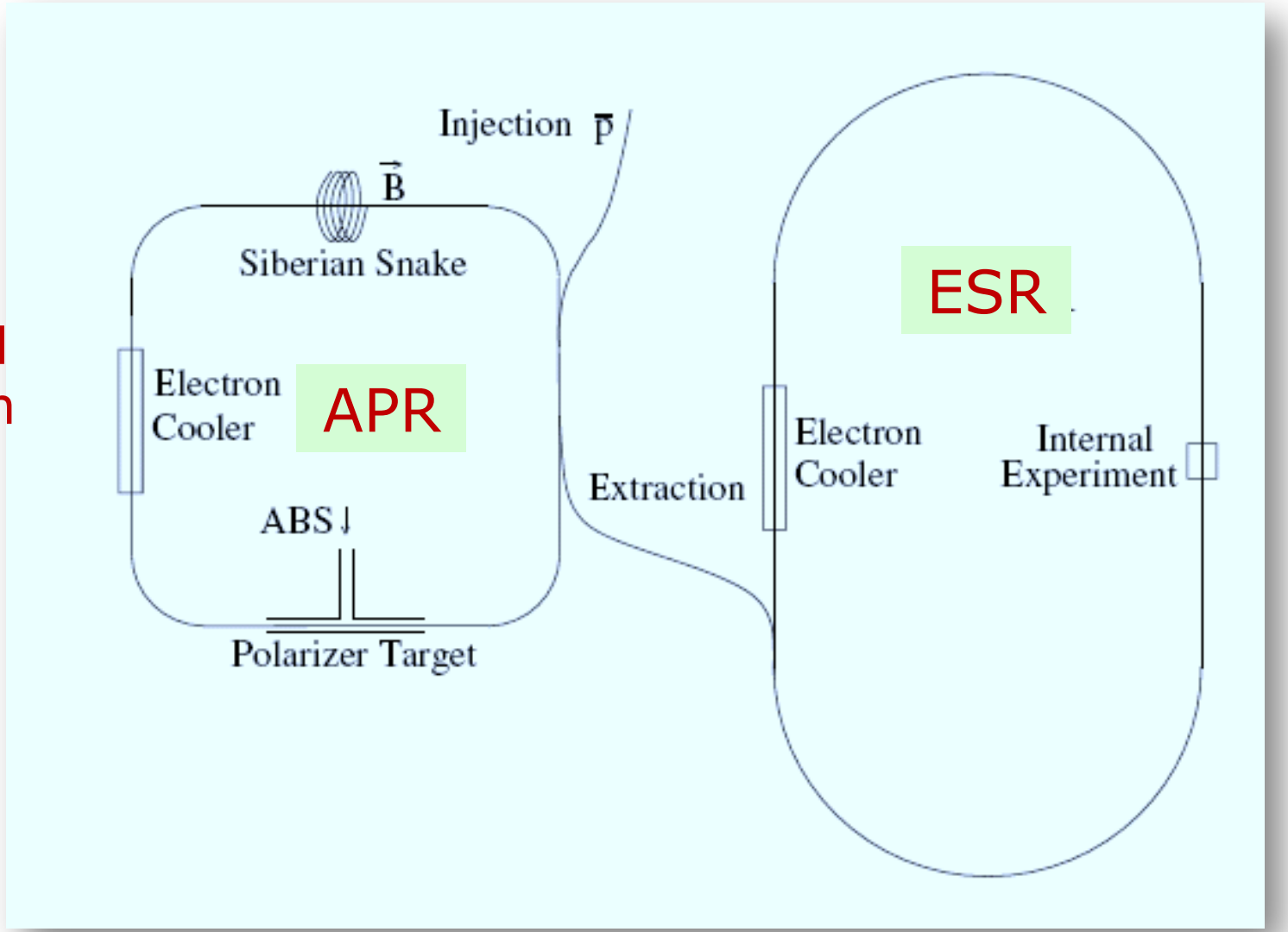
PAX@FAIR

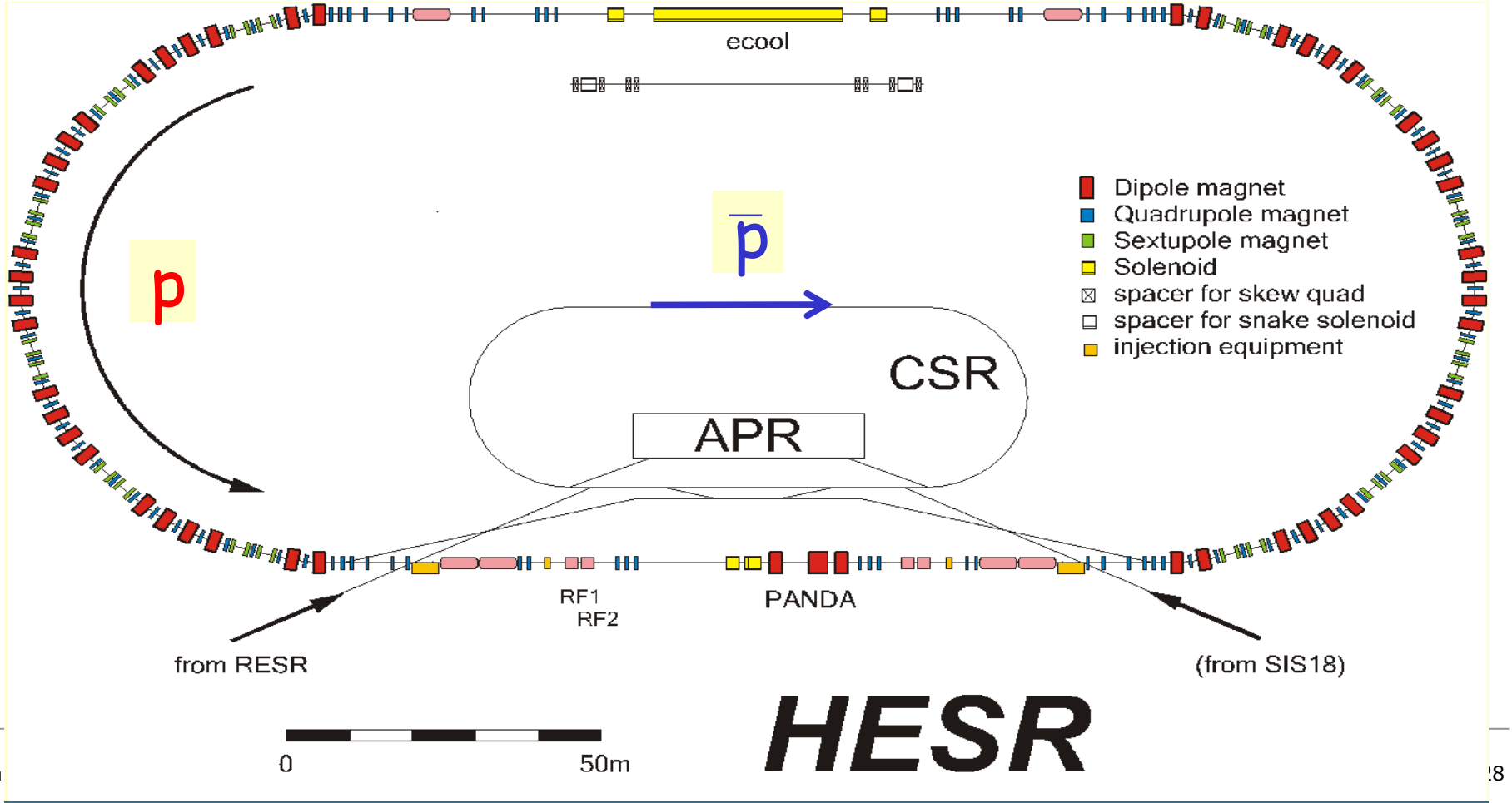
PAX proposal for FAIR – fixed target mode

APR: Dedicated Antiproton Polarizer Ring



PAX proposal for HESR upgrade

- polarized antiproton-proton collider



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Summary –
Missing tool – Polarized antiprotons

- ✧Achievements by the PAX Collaboration
- ✓Commissioned the new PAX facility at COSY for implementation at CERN/AD
- ✓Disproven the usefulness of a co-moving polarized lepton beam as polarizer of hadron beam "spin flip method"
- ✓Confirmed the spin filtering method as the viable method for polarization of a stored hadron beam "spin filter method"
- ❑PAX@CERN/AD - measurement of the spin-dependent pbar-p interaction is mandatory as a first step towards polarized antiprotons
- ❑NuPECC LRP2010/Future Facilities:"...specifically promote → The Technical Design Study for a polarised proton-antiproton, PAX ...collider …at FAIR."

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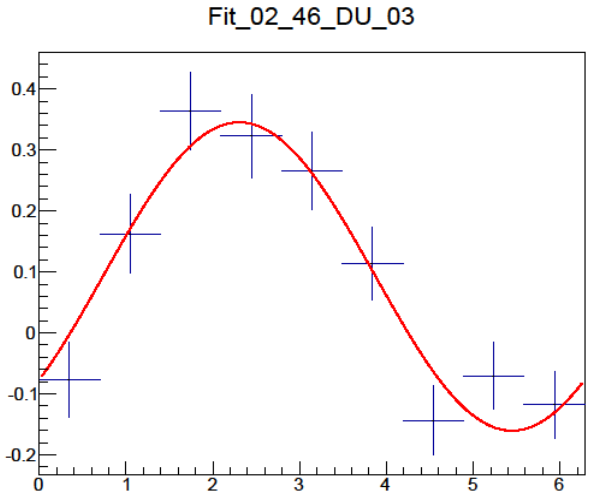
PAX in parallel – spin and precision as selection tools

- **TRIC** - Time Reversal Invariance at COSY [Prop. 215]
  - **Test of Time-Reversal Invariance in Proton-Deuteron Scattering at COSY**
  - Spokespersons:

  P.D. Eversheim, B. Lorentz and Yu. Valdau

- Spin observables in a complete double-polarized proton deuteron breakup experiment [Prop 202.1]
  - For testing chiral effective field theory
  - As precursor of other forefront measurements with similar equipment
  - **Measurement of Spin Observables in the pd Breakup Reaction** Spokesperson: P.T.E

PAX in parallel: search for a permanent electric dipole – violating time & parity



Horizontal polarization as a function of the direction (0 to 2π)

- **EDM@COSY**
- Spokespersons: Ed Stephenson & Paolo Lenisa
  - **Extending the In-Plane Spin Coherence Time of a Polarized Deuteron Beam in a Storage Ring Using Higher Order Fields**

  [Cont. of Proposal 176]

- **JEDI** – Jülich Electric Dipole moment Investigations
- Spokespersons:
  - Andreas Lehrach, Frank Rathmann, Jörg Pretz
  - **Search for Permanent Electric Dipole Moments at COSY Step 1: Spin coherence and systematic error studies**

  [Proposal 216]

Tomonaga's "The Story of Spin"

- "[Spin] It is a mysterious beast, and yet its practical effect prevails over the whole of science. The existence of spin, and the statistics associated with it, is the most subtle and ingenious design of Nature

- without it the whole universe would collapse."

- Foreword by Takeshi Oka

Thank you for your attention!

Proposals for polarized antiproton beams

- CERN proposal CERN/PSCC/85-80 (Nov. 5, 1985)

E. Steffens et al, Proc. 3rd LEAR workshop Tignes 1985, p. 245:

Proposal for measurement of spin dependence of the interaction at low momenta

- PAX Collaboration - P.Lenisa and F. Rathmann et al.
- *Antiproton-Proton Scattering Experiments with Polarization,* arXiv:hep-ex/0505054 (May 2005)
- *Antiproton–Proton Scattering Experiments with Polarization, Update (Jan 2006)*

- CERN/AD letter-of-intent *Measurement of the spin–dependence of the p(bar)p interaction at the AD–Ring,* arXiv:nucl-ex/0512021 (Nov. 2005)
- CERN/AD proposal *Measurement of the Spin–Dependence of the $p\bar{p}$ Interaction at the AD–Ring,* CERN-SPSC-2009-012 ; SPSC-P-337 (April 2009)

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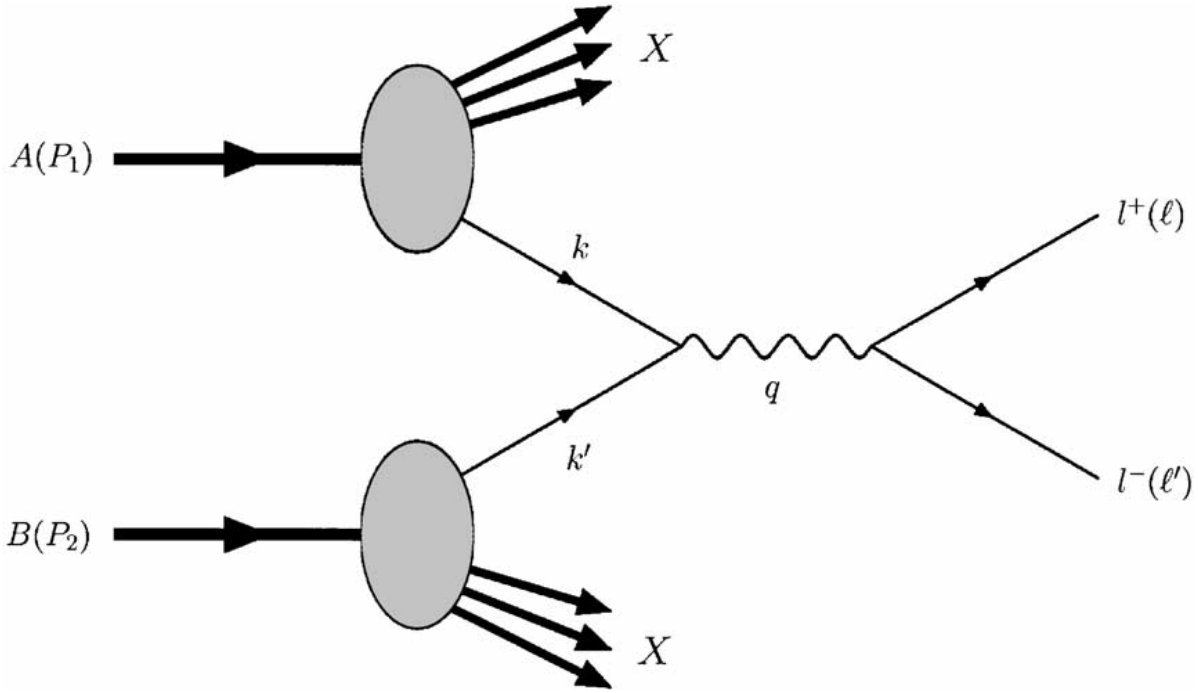
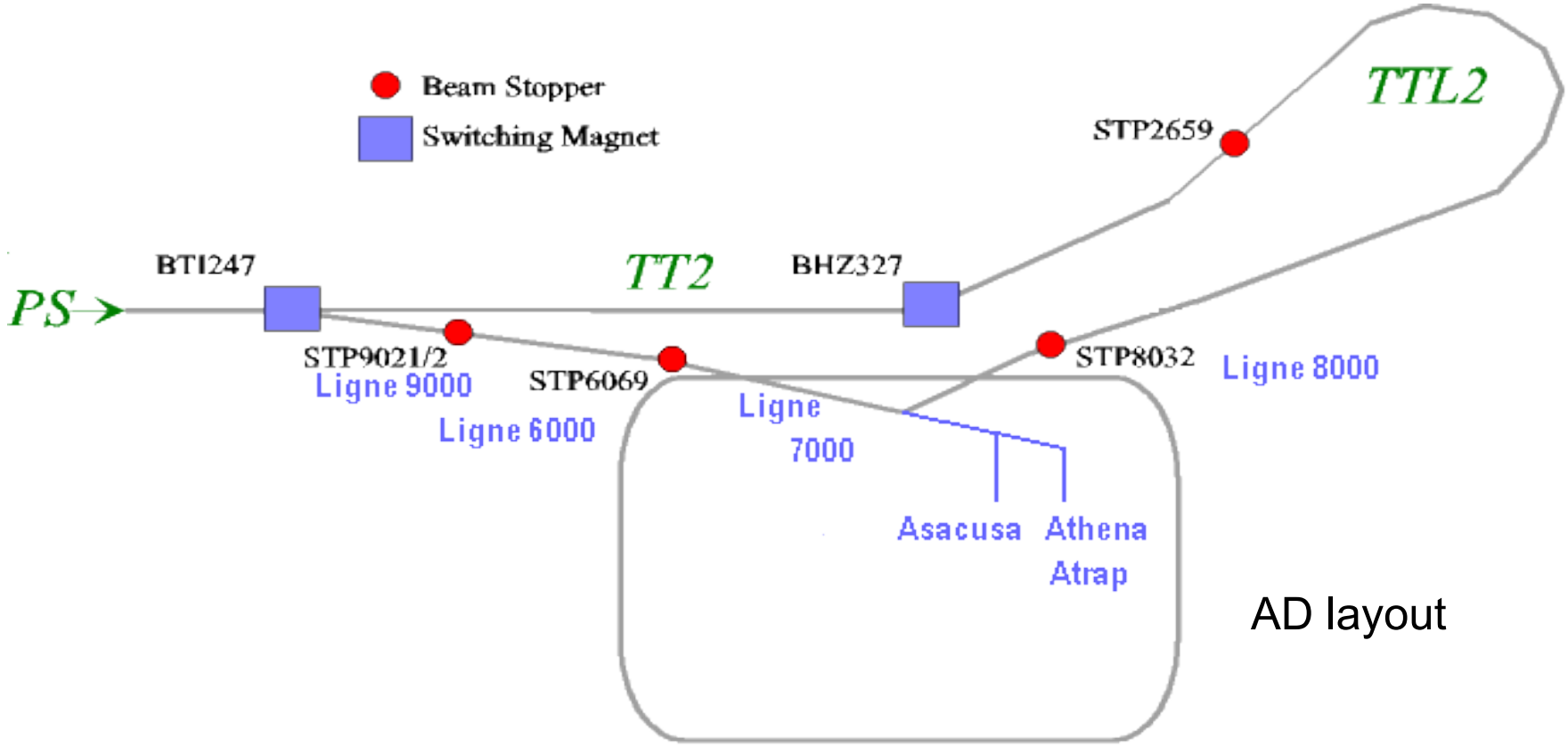
V. Barone et al. / Physics Reports 359 (2002) 1–168



PolAntiP – Aim

Complete characterization of spin-dependence of $p\bar{p}$ interaction

→ **CERN AD (the only place worldwide)**



AD layout

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